An Evaluation of Energy Recovery Potential from Flare Gases on Offshore Oil and Gas Facilities

by

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Dissertation submitted in partial fulfilment of
the requirement for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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in partial fulfilment of the requirement for the
MSc. PETROLEUM ENGINEERING

Approved by,

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(Dr. Mohd Shiraz Bin Aris)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Safuan Bin Abd Rahman

ABSTRACT

Gas flaring in the oil and gas industry is a process of burning excess natural gas in the atmosphere. It happens at the oil and gas onshore and offshore producing platform and its processing plant. As such, there is considerable amount of natural gas being wasted. It would be highly desirable to recover energy from flared natural gas to generate electricity especially in the offshore setting where electricity is not readily available. Hence, more attention should be focused on the effective utilization of flared natural gas in oil and gas offshore platforms. The energy recovery system, as one of the promising techniques, has been attracting increased attention to generate electricity from flared natural gas in the Duyong Central Processing Platform (DCPP). In this study, a simulation model has been developed by using the HYSYS software to predict the potential energy in terms of power generated from gas flaring in DCPP by using a microturbine. The principle focus that has been put forward is to recover and evaluate the potential energy from gas flaring where the case study is set at Duyong Central Processing Platform. Currently, the total amount of gas being burned at DCPP is amounted to 1.56MMscf/d. A total of 244kW of power could be generated with the aid of the simulation model. A thorough economic evaluation has been done based on the power generated and the capital required for the system setup. It is concluded that the energy recovery system is highly desirable where an amount of RM217,344 could be saved annually over a payback period of 7 years. It is recommended that an energy recovery system consists of a microturbine were installed in Duyong Central Processing Platform to utilise the gas flaring

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ABBREVIATIONS

ADNOC	Abu Dhabi National Oil Company
AEUB	Alberta Energy and Utilities Board
GGFRP	Global Gas Flaring Reduction Partnership
GHG	Green House Gases
GTL	Gas to Liquid
IRR	Internal Rate of Return
KOC	Kuwait Oil Company
MARR	Minimum Attractive Rate of Return
PW	Present Worth
UNFCC	United Nations Framework Convention on Climate Change

CHAPTER 1

INTRODUCTION

1.0 Introduction

Natural gas is a hydrocarbon gas consisting primarily of methane, with other hydrocarbons such as ethane, propane, and butane. It may also contain Nitrogen and considerable amounts of acidic gases, such as, carbon dioxide and hydrogen sulphide. Other composition, such as, water and mercury may exist according to the natural deposit from which the natural gas is extracted. During the oil and gas production process, it is common that excess natural gas being burned in the air in a process called gas flaring.

Gas flaring is among the main issues being discussed in the oil and gas industry in recent years. According to World Bank statistics, the amount of gas flaring in the oil and gas industry throughout the world in 2003 is 108 billion cubic meters which is as much as France and Germany combined yearly industrial consumption [1]. While this alarming numbers is from hydrocarbon processing plants and petrochemical plants as well, it is the upstream segment e.g. oil and gas production platforms that contribute the largest in term of gas being burned.

In the oil and gas producing and processing facilities, flaring is often necessary and viewed as an effective and safe method of natural gas disposal whenever excess pressures should be released to prevent equipment failures on major upset conditions.

The current research is motivated by concerns over the environmental impact associated with gas flaring activities in both onshore and offshore facilities. Flaring has impacts on global warming by the amount of carbon dioxide that it emits into the atmosphere. Besides that, the presence of nitrogen oxides in the burned gas can significantly deplete the ozone layer. Furthermore, sulphur dioxide that escapes the flare stack contributes to acid rain. In addition to that, there will also be resource depletion due to natural gas being burnt [2].

Generating electricity on offshore platforms is an attractive option because most of the offshore platforms use significant amounts of electricity. Electricity is required to run nearly every piece of equipment on the offshore platform. This study explores and evaluates the energy recovery potential from flare gases on Duyong Central Processing Platform. The study will focus on both the technical and economic aspects of energy recovery from the otherwise flared gas on this platform.

1.1 Gas Flaring

Gas flaring, normally in the open atmosphere is commonly used to manage unwanted gas and upset process conditions in the oil and gas industry [1]. A number of studies have highlighted the amount of natural gas was being flared around the world. In Nigeria, J.A.Sonibare reported that close to 90BCM of natural gas being flared between the years 1998 and 2002 [2]. Gusty Irdiani, in his research reported the amount of gas being flared in Indonesia is approximately at 120 million tons of CO_2 equivalent in 1990. The gas flaring amount in the country is accounted at 5% of its gas produced yearly[3]. While for Malaysia, Ajay Mehta from Shell Malaysia Exploration and Production (E & P) reported that the gas flaring has continuously been reduced since 2003 as can be seen in Figure 2 below as the result of continuous effort on reducing the gas flaring. Latest data showed that 4.2 million tons or 92 million tons CO_2 equivalent of gas was flared in 2007[4].

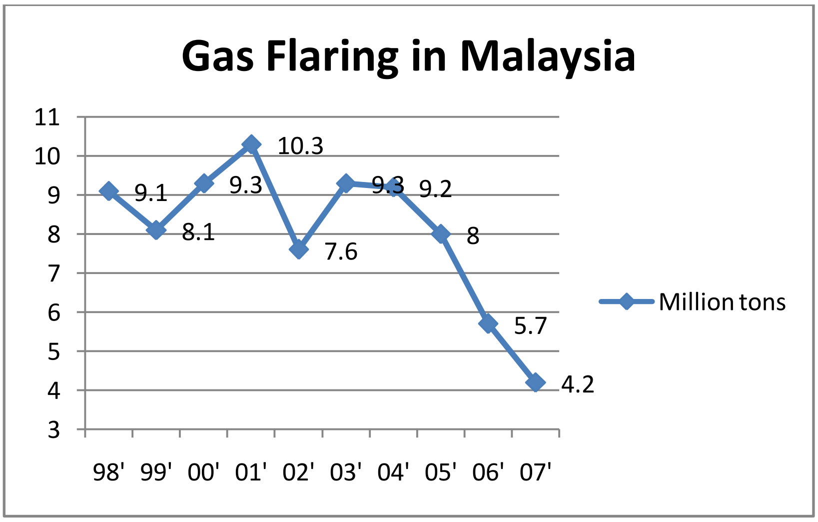


Figure 1: Tabulate Data for Gas Flaring in Malaysia*[4]*.

The reason behind the gas flaring practice being continuously happens is because gas flaring is not offending or breaking any rules. Furthermore, there is no obligation for the oil and gas companies to venture into the unstable gas market. As pointed by the Global Gas Flaring Reduction Partnership (GGFRP), the institutional, legal and regulatory framework for gas is still very limited. The deficiency of a proper frame of rules has led to chaos with the oil and gas companies pursuing their activities while the activist fighting from the side fuelling public protests and demonstrations. With in depth and comprehensive set of rules that limits the activity of gas flaring, both parties can conduct their work in peace and yield more productive results. In addition to that, there is a lack of eye catching incentives from the government in the form of tax structure and the effort to stabilize the market for gas and its products causes the lack of interest to develop and utilise the gas as a useful resource.

Among the primary motives for the flaring of gas that the export of flare gases is not typically pursued by the oil and gas companies due to the intermittent supply, quality of the flared gas and cost of transportation [5]. In addition to that, as mentioned by Alberta Energy and Utilities Board (AEUB), gas flaring is necessary during the completion and testing of natural gas wells or during the maintenance routine at gas complex. This can be due to the gas flaring has been viewed as an easy method of disposing the natural gas. Furthermore in many cases, the company is faced with a dilemma on whether or not to pursue gas flaring when the amount of solution gas in oil well is very small and the cost to produce it is much higher than the gas revenue. This is one of the predicaments the companies are confronted with when they have to make a call to protect their status as a business entity. Since safety, without a doubt is a subject of utmost importance, the mechanism to flare the gas has to be in place to control the pressure in a well or in a pipeline so that it can be monitored closely and carefully to avoid any mishaps that can lead to serious catastrophe.

In recent years, many companies around the globe are in the move to reduce gas flaring. For example, Shell aspires towards “Zero Continuous Flaring” through its E & P operations [4] and the Abu Dhabi National Oil Company (ADNOC) through several steps as mentioned in detail by Ihab Othman. Among others include, closing the well with high gas oil ratio (GOR), plant modification and flue gas heat recovery systems. The latter is where this study is primarily focused on and will be described in detail in the following sections.

1.2 Energy Recovery

Energy recovery is based on the principle of utilization of a common source. An example of energy recovery of a common source is in the heat source from a steel mill plant in a cold country which the heat from the mill can be sold and used to heat up houses and offices in the surrounding area. In this case the input mass flow comes from the surrounding in which, being at ambient temperature, are at a lower temperature than the waste stream, e.g.: from the mill. Thermal energy is often recovered from liquid or gaseous waste streams and can be used to heat up water intakes of a building for heating, ventilating and air conditioning (HVAC) systems or a process system in a plant.

As mentioned earlier, Ihab Othman from ADNOC has addressed the flue gas heat recovery system as a step to reduce gas flaring. This is one example of heat recovery in the oil and gas industries where electricity has been saved while flaring gas is fully utilized before it goes to the flare stack. He suggested the utilization of heat from turbines and power generators to heat the hot oil system network and estimated an amount of 7.0 MMSCFD of gas can be conserved. It is unclear where the value came from and how the system will be implemented. However, it is a relatively easy and practical way to utilize the available energy in a plant[6].

Other than that, another method to recover energy and at the same time reduce gas flaring has been reported in a work by Rahimpour et. al. which is related to this study. The method is to generate electricity with the flare gas as the fuel. As electrical power is the most widely used form of energy especially in a plant environment, the electricity generated can be used to power up some critical equipment on the plant. In the case of Asalooye gas refinery where the Rahimpour case study was taken, the amount of gas being flared was 300,000kg/h and most of it is Methane (80% in mass fraction)[7].

1.3 Energy Evaluation

Interestingly in the last several decades, energy has significantly increased in terms of demand as the world population grow and this has caused the significant rise of energy prices. The growing demand of energy coupled with the difficulties of finding non-renewable energy sources such as natural gas and oil should only cause the energy cost to continue rising. This affects most of the industries as energy accounts for a huge chunk of their expenses even for the oil and gas industry. Now days, companies worldwide are in the move to install and use better technology to reduce their energy consumption. However, modification of existing plants with the latest energy saving equipment has become a great challenge as it involves significant capital. Thus the energy evaluation becomes a must before any project kicks off.

An economic evaluation for a new energy recovery program needs some of the economic tools such as the rate of return and payback period[7]. Questions such as how much can be saved, how long will it take to get back the money, and how much initial capital is required can be answered with the economic analysis and detail cost assessment study of the project.

1.4 Problem Statement

Gas flaring becomes a big issue nowadays as the world faces global warming issues from the rise of carbon dioxide and greenhouse gases (GHG) concentration in the atmosphere. Hence, PETRONAS as well as other leading oil and gas company in the world are moving toward reducing the emission of CO2 through minimizing gas flaring on their exploration and production facilities. It is for this same reason why this project is important. The case study selected for this project will involve the gas flaring activities on this one of PETRONAS' gas platform in the east coast of Malaysia namely Duyong Gas Complex. In this project, data from the Duyong Gas Complex or to be more specific the Duyong Central Processing Platform as seen in the Figure 2 below, were obtained and evaluated for its recovery potential. Typically, the total gas being flared in the Duyong gas platform is approximately 1.56 MMscf/d on a daily average basis. This can be considered to be a huge loss of untapped energy which could have been used in electricity generation. This project attempts to explore and evaluate the energy potential from the gas flaring activity on this facility.

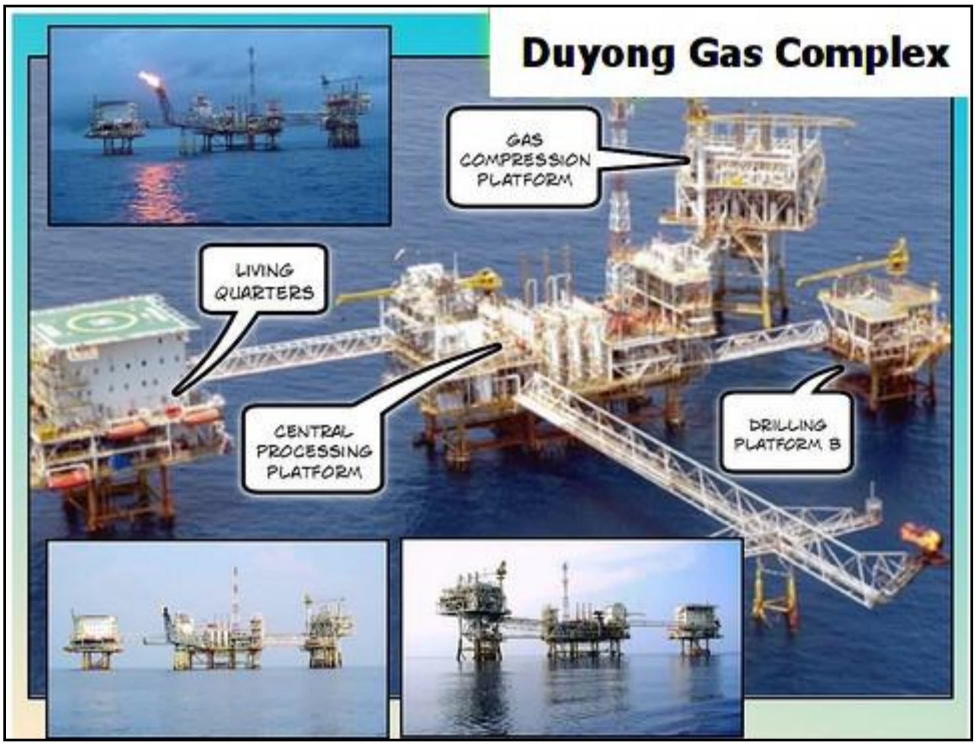


Figure 2: Aerial View of Duyong Gas Complex

1.5 Objectives of Study

The project objectives are to prove the commercial viability of transforming otherwise flared and wasted natural gas into electricity for the Duyong Central Processing Platform.

Firstly, this study will evaluate and explore the use of flare gas for electricity generation. The recycled energy has the additional benefit of being generated on production sites where the majority of their electric load is consumed. Furthermore, the utilization of flared gas will help to conserve the valuable energy resources, improve the oil and gas industry's environmental stewardship and improve overall air quality in the process.

Secondly, this study will demonstrate the process of electricity generation from natural gas in a process simulation software called HYSYS. The software will help on estimating the electric power that could be generated from the flared gas on the Duyong Central Processing Platform.

1.6 Scope of Study

In this study, data for the pilot flare from PETRONAS Gas Platform located offshore Terengganu named Duyong Central Processing Platform within the Duyong Gas Complex was obtained. In this platform, the gas is fed from Duyong Drilling Platform B (DDP-B) which is within the complex as can be seen in Figure 1 above, Pulai A, Ledang and the West Natuna fields. The gas from Pulai A, Ledang and West Natuna will undergo a separation process in Duyong Receiving facility and will then be combined with gas from DDP-B after the low pressure (LP) and high pressure (HP) knock out drums before being routed to the flare boom. At the same time, the facilities on the Duyong Gas Complex also use the gas from West Natuna as fuel gas to power-up the existing gas turbine generator.

A simulation software called HYSYS version 3.2 will be used to simulate the process of energy conversion from microturbine.

CHAPTER 2

THEORY AND LITERATURE REVIEW

This chapter will describe in detail the fundamental and history of natural gas since gas flaring is basically a process of flaring the unwanted natural gas in the air. Subsequently this chapter will describe a microturbine that has been selected in converting energy in the natural gas and process simulation on electricity generation by using the microturbine.

2.0 Fundamental of Natural Gas

Natural gas is colourless and odourless in its natural form. It is combustible and gives off a significant energy in the form of heat when burned. Unlike other fossil fuels, however, natural gas is a relatively clean gas as it emits lower levels of potentially harmful by-products into the air during combustion. The importance of energy is its various forms has been presented in the previous chapter. It is this increasingly demand of energy that has elevated natural gas to such level of importance in our society and lives today[8].

For hundreds of years, natural gas has been known as a very useful substance. The Chinese discovered a very long time ago that the energy in natural gas could be harnessed, and used to heat water. In the early days of natural gas industry, the gas was mainly used to light streetlamps, and the occasional house. However, with much improved technologies advancement and distribution channel, natural gas is being used in most sectors such as, industrial, electricity generation, transportation and residential sectors[9, 10]. In this study, the usage of natural gas for electricity generation is showed by using a microturbine.

Table 1 shows a typical composition of natural gas produced from the earth crust. This composition ranges should be expected when dealing with the untreated natural gas. The specific composition of natural gas for the Duyong Central Processing Platform will be described in the previous chapter.

Table 1: Typical Composition of Natural Gas[8].

Composition	Molecular Formula	Percentage (%)
Methane	CH_4	70-90
Ethane	C_2H_6	0-20
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8
Oxygen	O_2	0-0.2
Nitrogen	N_2	0-5
Hydrogen Sulfide	H_2S	0-5
Other Gases	A, He, Ne, Xe	trace

2.1 Electricity Generation by Using Micro Turbine

Since 1980s, gas turbines have been used in the oil and gas industry to drive multiple generators for electricity generation. In the late 1990s, recuperator was introduced in gas turbine design. The recuperator was positioned within the supply and exhaust air streams of gas turbines as shown in Figure 3 in order to recover the waste heat and hence boost up the efficiency of small gas turbine which is commonly referred as microturbine and make these smaller package reliable to produce power[11]. Microturbine is a small single-shaft gas turbine equipped with centrifugal compressor, radial turbine, combustion chamber and recuperator[12]. It is increasingly in demand for power generation in offshore platform and oil and gas facilities in remote areas.

The heart of the microturbine is the compressor-turbine package, which is commonly mounted on a single shaft along with the electric generator as shown in Figure 3. Two bearings support the single shaft. The single moving part of the microturbine reduces the maintenance needs and thus enhancing the overall reliability. Disadvantages found in microturbine are low-fuel-to-electricity efficiency and the power output and efficiency reduced with in high ambient temperature. The size range for microturbines available is from 30 to 1000 kilowatts (kW), while conventional gas turbine sizes range from 500kW to 350 megawatts (MW). The weight range for microturbines is from 0.5 tonnes for 30 kW model and up to 1.7

tonnes for 1000 kW model. The physical dimensions range for microturbine can be as small as 1.9m x 0.7m x 1.3m for 30kW model and can be as big as 2.4m x 9.1m x 2.9m for 1000kW model.

Specifically for offshore platform, it has the advantage on space, serviceability, ability to work in salt water and explosive environment as classified by the US National Fire Protection Association. The US National Fire Protection Association has classified microturbines operating in oil and gas platform as class I, division II. Microturbines manufacturer like Ellliot Energy Systems Inc and Capstones have the class I, division II rating[13].

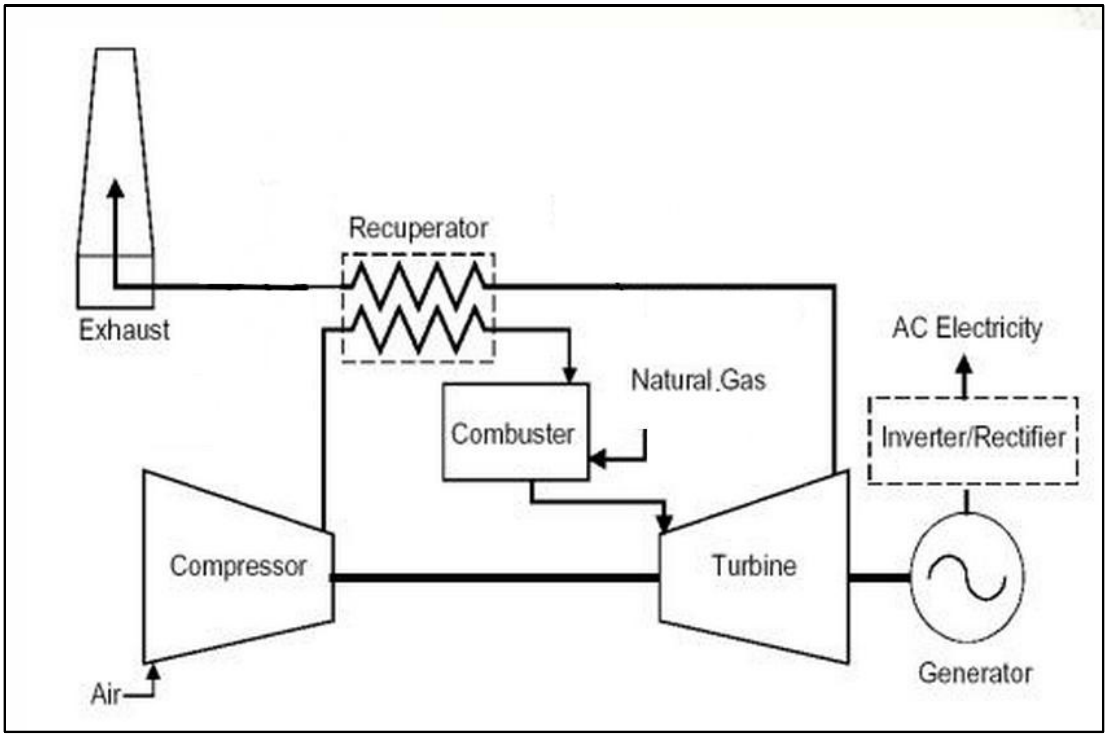


Figure 3: Microturbine System

2.2 Process Simulation

In order to evaluate the potential energy recovery in a process set-up, commercial simulators such as Aspen Plus, Aspen Dynamics, PRO II, Dynsim or HYSYS are available. HYSYS software has been chosen as simulators for this project since it is the most commonly used and readily available in Universiti Teknologi Petronas lab.

2.2.1 HYSYS Process Simulation Package

HyproTech HYSYS 3.2 is a powerful software that will be used to simulate and later evaluate the potential energy of the flaring gas. It can be used for steady and dynamic state simulation processes. It includes tools for estimation of physical properties and liquid-vapour phase equilibrium, heat and material balances, design, optimization of oil and gas processes and process equipment. The program is built upon proven technologies, with more than two decades of supplying process simulation tools to the oil and gas industries. HYSYS is an interactive and flexible process modelling software which allows engineers, students and researchers to design, monitor, troubleshoot; perform process operational improvement and asset management. This will enhance the productivity, reliability, decision making and profitability of the plant life cycle.

In HYSYS, all necessary information pertaining to pure components flash and physical properties calculations is contained in the fluid package. However, choosing the right fluid package for a given component and condition is essential. Proper selection of thermodynamic models during process simulation is also absolutely necessary as a starting point for accurate process modelling. A process that is otherwise fully optimized in terms of equipment selection, configuration can be rendered worthless if the process simulation is based on inaccurate fluid package and thermodynamics models. For energy recovery from the flaring gas simulation, Peng-Robinson fluid package is suggested by [9] for its accuracy and applicability.

Once the fluid package and the thermodynamics model equations are selected, it is now possible to enter the simulation environment where the detail process flow diagram can be constructed. In HYSYS, stream to stream connection is impossible and components such as mixer and splitters are use to produce satisfactory model and though this have little or no effect on the accuracy of the process under investigation. Simulation of the built process flow diagram is achieved by supplying some important physical, thermodynamics and transport data to the stream and equipment involves, this is done until all the units and the streams are solved and converged, e.g.: showed by green colour on the stream and equipment.

HYSYS require minimal input data from the user, the most important input parameters needed for streams to solve are the Temperature, Pressure and flow rate of the stream.

HYSYS offers an assortment of utilities which can be attached to process stream and unit operations. The tools interact with the process and provide additional information automatically. For instance, the flow sheet within HYSYS simulation environment can be manipulated by the user to get the desired output.

2.2.2 Steady State and Dynamic Simulation

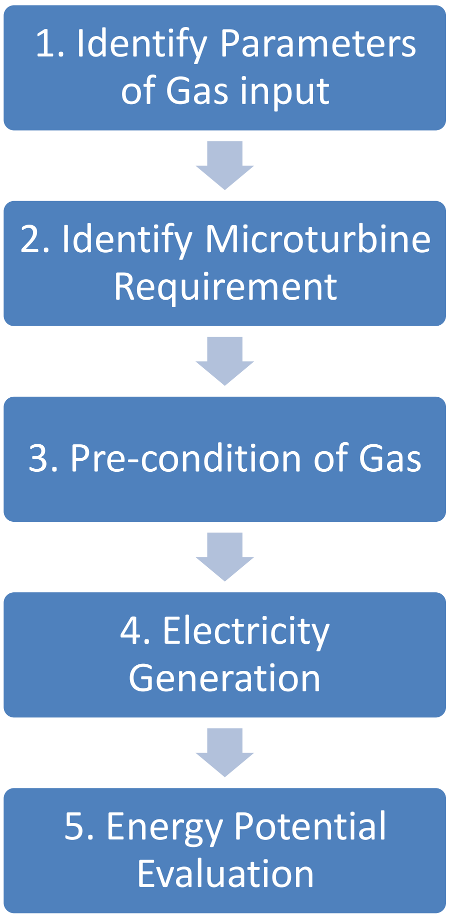
It has been mentioned earlier on the capability of HYSYS software to run on steady state and dynamic simulation process. As this project rely on the simulation result supported by the work of others, it is still important to make sure everything is right from the start. The issue of which to use has been reported by [14] through a research paper titled chemical plant flare minimization via plantwide dynamic simulation. Basically, the work is on flare minimizing for chemical plant start up operation model where in the chemical plant industry, flaring is crucial for the plant safety. However, excessive flaring especially during the start up operation becomes a major concern. The work reported some studies on steady state simulation on start up operation of chemical plant based on predicted set of steady state operating points to project the system dynamic response. However, the method found to be lacking because of the missing piece between two adjacent steady state operating points and thus lacking the capability to guide the critical process control and operation[14]. For this project, steady state simulation is used because firstly, it is relatively simple compare to the inherent complexity of the plantwide dynamic simulation. In addition to that, the nature of the offshore platform is different from the chemical plant where shut down is not a common procedure. Further work on dynamic simulation is however still recommended to take into account external operational factors affecting the process.

CHAPTER 3

METHODOLOGY

This chapter describes in detail the methodology of this work and is divided into two sections. The first section will identify the parameters of gas input and fuel gas requirement for the microturbine such as gas heating value, gas components limit, contaminants limitation and sour gas limitation. Second section is the simulation part which is done to quantify the energy potential from the flare gas and thus economically evaluate the feasibility of the whole project should it be implemented.

3.1 Project Flow Chart



Data from Duyong Central Processing Platform:

- Gas properties, e.g. Pressure, Temperature
- Gas components
- Gas Heating Value

- Requirement on gas heating value
- Gas components limit
- Fuels contaminants limitation
- Sour gas limitation

To meet the microturbine requirement

- Electricity generation by microturbine in HYSYS

- Economic evaluation of energy recovered

Figure 4: Process flow of energy evaluation from flaring gas.

This study starts with the information on natural gas parameters obtained from the Duyong Central Processing Platform (DCPP), specifically from a tapping point on DCPP just before the natural gas being routed to the flare stack. The tap point was identified as suitable for this study by an engineer working in DCPP.

The flare gas has to pass through the gas pre-conditioned section to comply with the microturbine requirements before it pass through the electricity generation section. The processes involve in the electricity generation would be simulated using the HYSYS software to find the amount of energy that could be recovered. Finally, the economic tools would be used to economically evaluate the project.

3.1.1 Identify Parameters of Gas Input

It is necessary to know the parameters of the gas such as the natural gas properties, gas components and its heating value before it can be used as fuel in the microturbine to generate electricity. In this study, the natural gas properties and gas components taken from the tapping point on Duyong Central Processing Platform (DCPP) was identified as follows.

Table 2: Gas properties from the tapping point on the DCPP

Pressure	**1003kPa**
Flow rate	1.56 MMscf/d
Temperature	37.17^{o}C
Heat Flow	5.978 X 10^{6} kJ/h
Higher Heating Value (HHV)	1054.50 Btu/sf3

Table 3: Gas components from the tapping point on the Duyong Central Processing Platform

Component	Mass fraction
Methane	83.1413
Ethane	9.697911
Propane	1.856903
n-butane	0.448056
i-butane	0.587834
n-pentane	0.015655
i-pentane	0.029646
Hexane	0.004939
Heptanes	0.049899
Octane	0.032335
Nonane	0.00066
Carbon Dioxide, CO_2	3.637937
Nitrogen, N_2	0.49561
Water, H_2O	0.001309
Hydrogen Sulfide, H_2S	0.00001

The step of indentify the parameters of gas input provides the base of this study where the properties and gas components of current and projected gas flaring were assumed to be fixed.

3.1.2 Identify Microturbine Requirement

It is necessary to identify and comply with the microturbine requirement to avoid problems that may affect the equipment performance, life, reliability, warranty and the most important is the safety. In this study, CR200 model microturbine from Capstone Turbine Corporation (Capstone) will be used as a tool in converting the potential energy in the natural gas where the fuel requirement data were taken from its technical reference.

3.1.2.1 Requirement on Gas Heating Value

The gas heating value will influence the amount of fuel consumed per kilowatt-hour of power generated, a low gas heating value will require large volumetric flows which can be uneconomical[12]. In other words, a modification of the existing microturbine is needed when using a low gas heating value as a fuel to make the microturbine work smoothly.

Table 4: Requirement on Gas Heating Value

Fuels type	Gas Heating Value (HHV)	
	Calorific Value Btu/ft^3 (MJ/m^3)	
	LSL	USL
Natural Gas	825 (32.5)	1275 (50.2)

Source: Technical Reference:Capstone MicroTurbine Fuel Requirements

The Higher Heating Value (HHV) was calculated as follows:

HHV of natural gas = $\sum_{i=0}^{n} x_i \, \mathrm{HHV}_i$ ………………………………………….Eq. (1)

Where: HHV_i = Higher Heating Value of gas component *i*, in Btu/ft^3

x_i = mole fraction of gas component *i*

Table 5: Calculation for Higher Heating Value (HHV) for natural gas from the tapping point on the DCPP

Component	**Mass fraction**	**Mole Fraction, *x***	**HHV (Btu/ft^3)**	***x**HHV (Btu/ft^3)**
Methane	83.1413	0.9145	1010	923.65
Ethane	9.697911	0.0569	1770	100.71
Propane	1.856903	0.0074	2516	18.62
n-butane	0.448056	0.0014	3262	4.57
i-butane	0.587834	0.0018	3252	5.85
n-pentane	0.015655	0	4009	0
i-pentane	0.029646	0	4001	0
Hexane	0.004939	0.0001	4756	0.48
Heptanes	0.049899	0	5503	0
Octane	0.032335	0.0001	6249	0.62
Nonane	0.00066	0	6997	0
Carbon Dioxide, CO_2	3.637937	0	0	0
Nitrogen, N_2	0.49561	0.0146	0	0
Water, H_2O	0.001309	0.0032	0	0
Hydrogen Sulfide, H_2S	0.00001	0	637	0
	Sum	1.0000		1054.50

The HHV calculated which is 1054.50 Btu/ft^3 is within the limit of the fuel requirement for the turbine. Hence the gas can be used for the microturbine.

3.1.2.2 Requirement on Major Gas Component Limits

The major gas component such as Methane (C1), Ethane (C2), Propane(C3), Butane(C4), Pentane(C5), Hexane(C6), Heptanes(C7), Octane(C8), Nonane(C9), Carbon Dioxide(CO_2), Nitrogen(N_2), Water(H_2O) and Hydrogen Sulphide (H_2S) in the fuel are usually determined by gas chromatography per ASTM D1945. Major gas components will determine the maximum power and efficiency that can be obtained by the microturbine.

Table 6: Requirement on Major Gas Component Limits

Fuels Type	Major Gas Component Limits (vol %)													
	C1		C2		C3		C4		C5	C6	N_2	CO_2		O_2
	LSL	USL	LSL	USL	LSL	USL	LSL	USL	USL	USL	USL	LSL	USL	USL
Natural Gas	50	100	0	14	0	9	0	4	1	1	22	0	11	6

Source: Technical Reference:Capstone MicroTurbine Fuel Requirements

3.1.2.3 Requirement on Fuels Contaminant Limitations

Gas input must be in accordance with the contaminants limitations listed in the table below. Contaminants such as water and lubricating oil droplet and dust will adversely affect the microturbine long-term performance and may result a shorter equipment life span.

Table 7: Gas input contaminant limitations

Contaminant	Units	USL	Test Method(1)	Notes
Lubricating Oil	ppm, mass	2	-	-
Particulate Size	microns	10	-	-
Particulate Qty	ppm, mass	20	-	-
Water	% mass liquid	0	ASTM D5454	-

Source: Technical Reference:Capstone MicroTurbine Fuel Requirements

Notes:

1. Or equivalent test method
2. Nominal trace specification
3. If other contaminants are present at more than 0.5 ppm by mass, they may need treatment, precautions and/or modifications

3.1.2.4 Requirement on Sour Gas Limitations

Microturbine operation on gaseous fuel may have limitations for hydrogen sulphide (H2S). Gaseous fuel with less than five parts-per-million by volume (ppmv) or often called “Sweet” while fuels with more than 5 ppmv are often considered “Sour” fuels. For CR200 model, the upper specification limit for hydrogen sulphide is 5000ppmv.

3.1.3 Pre-Conditioning Of Gas Input for Microturbine

The gas treatment for microturbine typically comprises of gas reception facilities, acid gas removal and disposal section, hydrogen sulphide (H_2S) scrubber, gas dehydration, particle filtration, and mercury removal. Although, there is no mercury content in the data taken from DCPP, the adverse effects of mercury existence make it compulsory to have mercury removal as a precaution in the gas treatment facility.

The gas reception facilities section provided for the removal of liquid entrainment in the system due to condensation and pressure reduction of the fluid (Joule Thomson effect). At this section, the gas inlet pressure is adjusted to meet the requirement of the gas turbine.

1. Acid gas removal and disposal section is provided to remove acid gases (CO_2 components) from the feed gas. The extent of removal is influenced by the specification and the requirement of the microturbine as discussed in the microturbine requirement section.
2. The dehydration section removes water from the feed gas. Water vapour must be removed to prevent corrosions, and water hammer.
3. Trace of mercury in the feed gas, which attacks piping, and equipment made from aluminium and aluminium compounds is removed in the mercury removal section. Filtration of the gas stream through the mercury removal unit is essential to prevent particle into the microturbine unit, thus prevent equipment from damage.

3.1.4 Electricity Generation

As mentioned earlier, the CR200 microturbine model from Capstone will be used in this study for electricity generation. Electricity generation is the process of converting electrical energy from the other forms of energy which in this case will be the natural gas as the fuel. The chemical energy stored in natural gas and oxygen from the air is converted successively into thermal energy, mechanical energy and finally electrical energy in the microturbine. Processes involved in the microturbine include the compression stage, combustion stage and the exhaust stage. These processes are simulated in the HYSYS software and the output which is the energy recovered is evaluated.

3.1.5 Energy Potential Evaluation

All engineering economy studies of capital projects should consider the return that a given project will or should produce. It is often that the high capital cost required makes the economic evaluation an important tool before any project is implemented. Before the economic evaluation can be done, it is important to quantify the potential energy that can be generated by the microturbine. The energy produced from the natural gas, which is otherwise being flared will be an important input for the overall assessment on the feasibility of the project.

In order to evaluate the economic profitability of the energy recovery project, three quantitative methods were used; Present Worth (PW) Method, Internal Rate of Return (IRR) method and payback period method. The first method evaluates the present equivalent worth by using interest rate known as Minimum Attractive Rate of Return (MARR) of 10%. The second method, which is the IRR method compute annual rates of returns, resulting from the initial capital required and will be compared with the MARR. Finally, the payback period is used to measure the speed with which the investments are recovered by the annual savings it produces. The final measure is equally important to complement the other two methods discussed earlier.

3.2 Simulation Modeling in HYSYS

Today, process simulation softwares are an essential tool in process industries. Indeed, simulation software play a key role in process development – to study process alternatives, asses feasibility and preliminary project economies, process design to optimize hardware selection, estimate equipment and operating cost and investigate feedstock flexibility; and plant operation to reduce energy use, increase yield and improve pollution control.

The simulation software used in this work is HYSYS 3.2. The process components in the proposed energy recovery scheme are evaluated based on the chemical reactions of the natural gas components in the mixer, combustion chamber and .

3.2.1 Assumption

A few assumptions have been made such as; process that takes place in the simulation is steady state, splitter has been used to represent the acid gas removal unit and H_2S scrubber with an efficiency of 100%.

To simplify the simulation as well as reduce computing time, a steady state condition was used. A large database on pure body component already incorporated into the software, hence simplify the simulation job.

3.2.2 Simulation Algorithm.

At the beginning of HYSYS simulation, pure components that are involved in the process were added in the Simulation Basis Manager (e.g:- Methane, Ethane and etc) with its corresponding mass fraction. The conditions of gas inlet into the microturbine that may anticipate in the process are defined as follow:

Table 8: Condition of gas inlet

Conditions	Value	Specification of gas inlet for micro gas turbine
Temperature (^oC)	37.17	-

Pressure (kPa)	1003	517-552
Molar flow (kgmol/h)	74.71	-
Mass flow (kg/h)	1318	-
Std ideal liq. vol. flow (m^3/h)	4.162	-
Molar enthalpy (kJ/kgmol)	8.001e+04	-
Molar entropy (kJ/kgmol ^oC)	168.9	-
Heat flow (kJ/h)	5.978e+06	2.4e+06

3.2.3 Simulation of Microturbine

In order to simulate the process in the microturbine in HYSYS, three components were needed; mixer to mix the air with the gas, combustion chamber, and turbine for electricity generation.

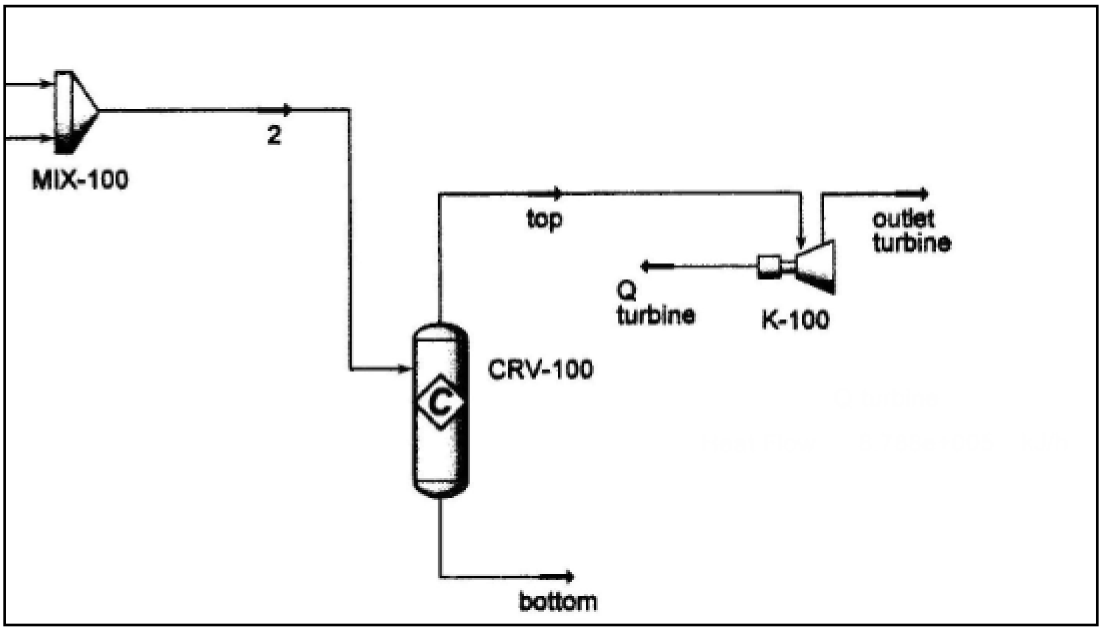


Figure 5: Component in HYSYS which represent gas turbine engine

3.2.3.1 Combustion chamber

An assumption was made in modelling the process happen in the gas combustion chamber. It is that the efficiency in the combustion chamber was 90 percent. In other terms, the output from the combustion chamber over the input and stated in terms of percentage.

3.2.3.2 Microturbine engine – Adiabatic efficiency for compressor

Another assumption made is that the compressor for the microturbine displays 75 percent adiabatic efficiency. When discussing the term adiabatic efficiency, the core meaning is that the external environment factors do not influence those of inside the turbine. The turbine is assumed to be a separate and independent entity, but stating it at 75 percent shows that natural external factors are still strongly influential. Looking at it in a particle basis where the research envisions the idea to being applied and not limited to theoretical understanding.

3.2.3.3 Acid Gas Remover Unit (AGRU)

Natural gas normally comes with CO_2, H_2S and other sulphur components, also commonly referred to as acid gas, which imposes great environmental hazards when released into the atmosphere and also damage the equipment on the processing facilities. Hence, there is a need to remove these unwanted components where the process is often referred to as gas sweetening process. There are many acid gas treating processes for removal of CO_2 which include the chemical solvent, physical solvent, adsorption processes, hybrid solvent and physical separation (membrane). The chemical solvent and physical solvent has been used widely in the oil and gas industry. The presence of carbon dioxide in the natural gas need to be removed in order to; increase the heating value of the gas, prevent corrosion of pipeline and gas processing equipment. Acid gas remover unit or AGRU is needed to remove the acidic components from the gas inlet. It is simply a vessel which sprays water from the top. The water will dissolve the acidic component and remove it at the bottom outlet. To represent this component in HYSYS, it has been replaced by the splitter with 100% efficiency. It means all the acidic gases were removed totally.

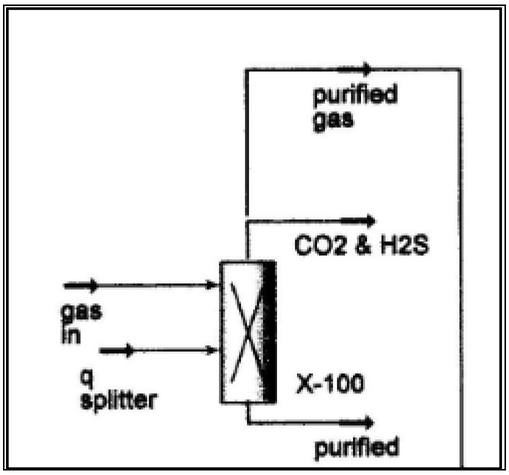


Figure 6: Splitter to represent Acid Gas Remover Unit (AGRU)

CHAPTER 4

RESULTS AND DISCUSSION

4.0 RESULTS

This chapter would discuss on two main findings. First section is the economic evaluation of potential energy from natural gas that otherwise being flared in Duyong Central Processing Platform by using a microturbine. The evaluation would shows commercial viability of the energy recovery program. Second section would evaluate the energy recovery potential should the energy recovery program being implemented in platforms supplying gas to Duyong Central Processing Platform, namely Pulai A and Ledang. It is worth to mention that besides the electricity generated, additional benefit of utilizing the flaring gas will positively reducing the flaring gas activity thus conserving the energy resources. Furthermore, the energy recovery from the flaring gas will help improve the oil and gas industry's environmental stewardship and improve overall air quality in the process.

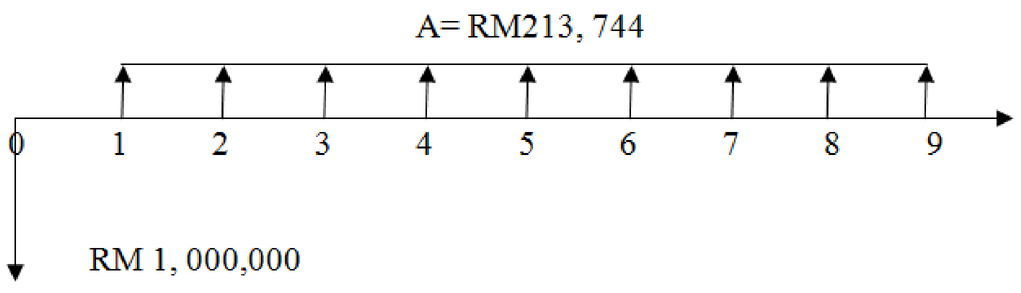
4.1 Economic Evaluation of Energy Recovery in DCPP

The aforementioned simulation model has been applied for energy potential analysis for DCPP and estimation of power that could be generated on the platform were presented in the table below.

Table 9: Summary of Electricity Generation for Duyong Central Processing Platform

Power generated (kW)	**244-325**
Adiabatic efficiency (%)	75
Usage percentage of gas supplied (%)	100
Input gas flow rate (MMscf/d)	1.56-2.0

A total power of 244 to 325 kW could be generated by the energy recovery system with the input gas of 1.56 - 2 MMscf/d. From the power generated, microturbine were chosen as an ideal gas turbine for the electricity generation with the estimated cost of RM900,000 (Capstone CR200 model). Considered the electricity unit price is RM0.10/kWh, and the total capital investment required around RM 1 million including cost of microturbine, installation and piping works, an estimated amount of RM 217,744 could be saved annually throughout the lifespan of microturbine.



Calculation for electricity generated in term of Ringgit Malaysia (RM):

RM 0.10/kWh X 244 kW X 24h/ day X 365 days = RM 213, 744

Figure 7: Calculation for Potential Annual Savings

4.1.1 Minimum Attractive Rate of Return (MARR)

The Minimum Attractive Rate of Return (MARR) is usually a policy issued by the top management of an organization considering the amount of money available for investment is always limited. MARR, which often called the hurdle rate, should be chosen to maximize the economic well being of an organization. One popular approach to establish a MARR involves the opportunity cost. Quite simply, the profit that could be gained should the money has been put into other investment vehicles or other profitable projects. In the process of evaluating the energy potential from the power generated by the microturbine, a MARR of 10% has been chose throughout the study period.

4.1.2 Present Worth (PW) Method

The PW method is based on the concept of equivalent worth of all cash flows relative to some base of beginning point in time called the present or simply said, at year zero. That is, all cash inflows and outflows are discounted to the present point in time at an interest rate that is generally the MARR. A positive PW of an investment project is amount of profit over the minimum amount required by investors. It is assumed that cash generated by the alternative is available for other uses that earn interest at a rate equal to the MARR.

To find the PW with the MARR of 10%, e.g.: *i*= 10% it is necessary to discount future amounts to the presents by using interest rate of 10%.

$PW (10\%) = F_0 (1+i)^0 + F_1 (1+i)^1+F_2(1+i)^2\ldots+F_9(1+i)^9$............................Eq. (2)

Since $F_1=F_2=F_3=F_4=F_5=F_6=F_7=F_9$, F_1 (1+i)1+F_2(1+i)2…+F_9(1+i)9 = A (P/A, 10%, 9)
Hence,

$PW (10\%) = F_0 (1+i)^0 + A (P/A, 10\%, 9)$

= -RM1, 000,000 (1+0.1)0+ RM 213,744 (5.7590)

= RM 230,951.60

Notes: (P/A, 10%, 9) = 5.7590, [15].

From the calculation above, with the MARR of 10% per year, the proposal of installing a microturbine instead of continue on gas flaring activity will add a sum of RM230,951.60 to the platform cash flow in 9 years ahead. Hence, the proposal of installing a microturbine to generate electricity from the gas flaring is a sound investment.

4.1.3 Internal Rate of Return (IRR) Method

The IRR method is the most widely used rate-of-return method for performing engineering economy analyses. It is often called with other names such as, profitability index and discounted cash-flow method. This method equates the equivalent worth of a project's cash inflows (savings) to the equivalent worth of cash outflows (expenditures, including investment cost) where the equivalent worth may be calculated using the present worth method. The decision rule of using the IRR method is when the IRR is greater than the MARR, the project is economically justified.

IRR can be computed as follows:

$$PW = 0 = -1\ 000,\ 000 + 213744\ (P/A,\ i'\%,\ 9)$$

$$i'\%, = IRR$$

Solve using the linear interpolation

At $i'\%= 15\%$, $PW = -1\ 000,\ 000 + 213744\ (P/A,\ 15\%,\ 9)$

$= -1\ 000,\ 000 + 213744\ (7.1078)$

$= 519249.6$

At $i'\%= 18\%$, $PW = -1\ 000,\ 000 + 213744\ (P/A,\ 18\%,\ 9)$

$= -1\ 000,\ 000 + 213744\ (4.3030)$

$= -80259.6$

The IRR is between the range of 15-18%, e.g.: (IRR= 15 %< i'<18 %)

The exact value of IRR can be computed as follows:

$$(18\%-15\%)/(519249.6-(-80259.6))= (i'\% - 15\%)/(519249.6-0)$$

$$i'\%= 17.59\%$$

IRR computed for the project is $i'\%= 17.59\%$

Notes: (P/A, 18%, 9) = 4.3030. (P/A, 15%, 9) = 7.1078, [16].

Since IRR of the project (17.59%) is greater than the MARR of the project (10%), it is concluded that the project is economically acceptable.

4.1.4 Payback Period Method

Payback period method, which is often called the simple payout method, mainly indicates a project's liquidity rather than its profitability. Historically, the payback method has been used as a measure of a project's risk, since liquidity deals with how fast an investment can be recovered[15]. In this study, it is equally important to determine how fast the capital outlay can be recovered. In other words, the payback method calculates the number of years required for cash inflows to equal cash outflows.

Table 10: Calculation of the Simple Payback Period and the Discounted Payback Period at *i* = 10% for Microturbine Installation in DCPP

End of Year (EOY), k	Net Cash Flow	Cumulative PW at *i*= 0%/yr through year k	PW of cash flow at *i*= 10%/yr	Cumulative PW at *i*=10%/yr through year k
0	-1000000	-1000000	-1000000	-1000000
1	213744	-786256	194315	-805685
2	213744	-572512	176638	-629047
3	213744	-358768	160589	-468461
4	213744	-145024	145988	-322474
5	213744	68720	132714	-189761
6	213744	282464	120659	-69103
7	213744	496208	109694	40592
8	213744	709952	99712	140303
9	213744	923696	90649	230952

Figure 8 above illustrate the simple and discounted cash flow throughout the project of microturbine installation in DCPP. Numbers in the first row or at year zero e.g.: k=0 represent the capital invested which is RM1, 000,000 and subsequent numbers in column 2 is the annual saving throughout the estimated microturbine lifespan of 9 years.

For simple payback period method, the number of years for the annual savings accumulated to equal the capital invested is at the end of year 5, e.g: EOY 5 since the cumulative balance turns positive at EOY 5. Similarly for discounted payback period, the number of years it takes for the annual savings to equal the capital invested is at the end of year 7, e.g.: EOY 7 taking into account the interest rate of 10%, *i*=10%.

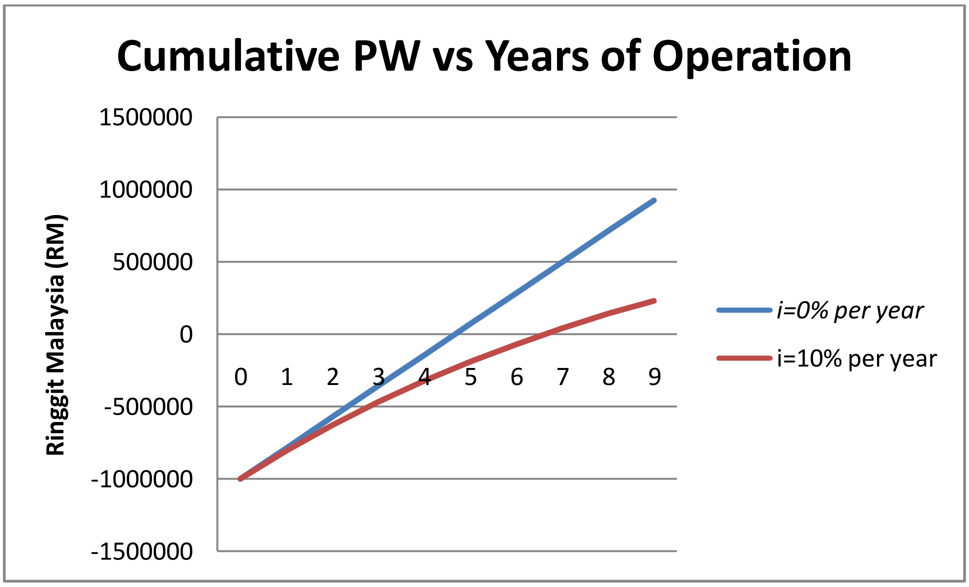


Figure 8: Graph of Cumulative PW for Microturbine Installation in DCPP

It is clearly shown by the blue trend line in the Figure 6 above, that simple payback period method e.g.: interest rate, *i*=0% will yield a payback period after 5 years. Quite simply, the time it takes for cash inflows, means yearly saving from the microturbine installation to accumulate and equal with the invested capital with no interest is 5 years.

Quite similar, for discounted payback period e.g.: interest rate, i=10% as shown by the red trend line, the payback period is later than the simple payback where the line cross the horizontal axis after 6 years. In other words, the time it takes for cash inflows or yearly savings from the microturbine installation to accumulate and become equal to the invested capital with interest rate of 10% is 7 years.

From both simple and discounted payback period, it is concluded that the proposal to install the microturbine is an attractive option since the payback period is less than the microturbine lifespan. Furthermore, the expected continuous saving after the payback period is a bonus should the microturbine be installed.

4.2 Discussion

Evaluation of energy potential in DCPP is shown to be commercially viable. It is important to see if the same technology could be implemented in the other two platform supplying gas to DCPP namely Pulai A and Ledang. The flow rate and gas parameters of natural gas available in the two platforms were assumed to be equal to DCPP. The gas compositions from the two platforms were added into the simulation and the summary of power generated was as follows:

Table 11: Comparison of Power Generated in Nearby Platform with the Main Gas Composition

Gas Components	Mass fraction		
	DCPP	Pulai A	Ledang
Methane	83.14	78.08	90.12
Ethane	9.70	8.23	7.34
Propane	1.86	1.22	1.01
n-butane	0.45	0.22	0.11
Power generated (kW)	244	220	260

It is summarize that Methane content as the major gas component in the natural gas is the main contributor for electricity generated. The conclusion is explained by Farzaneh in his work where the thermal efficiency of Brayton cycle reaches its maximum point as methane concentration increased[16]. Hence, an energy recovery program from the natural gas should highlight on the methane content to see if it will yield a high power output.

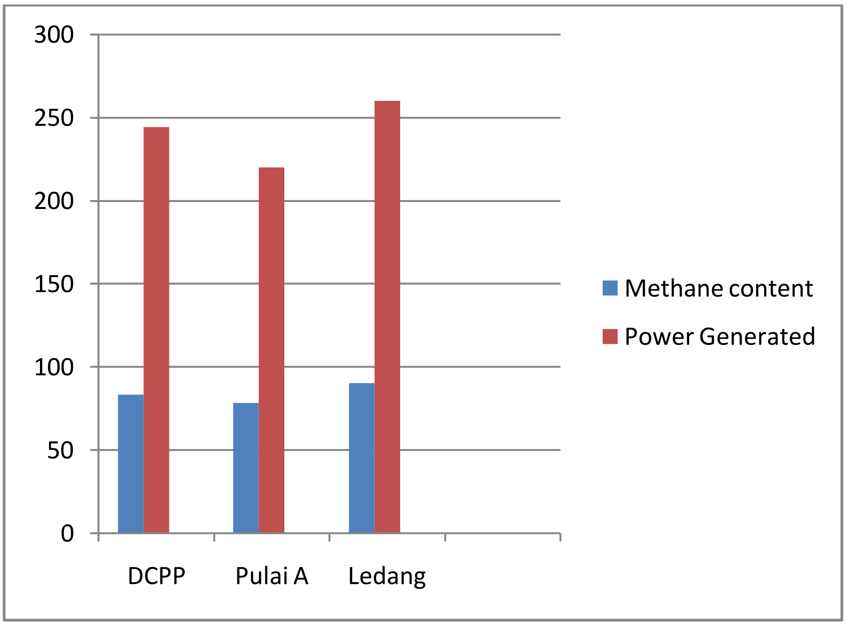


Figure 9: Comparison of Methane Content with Power Generated

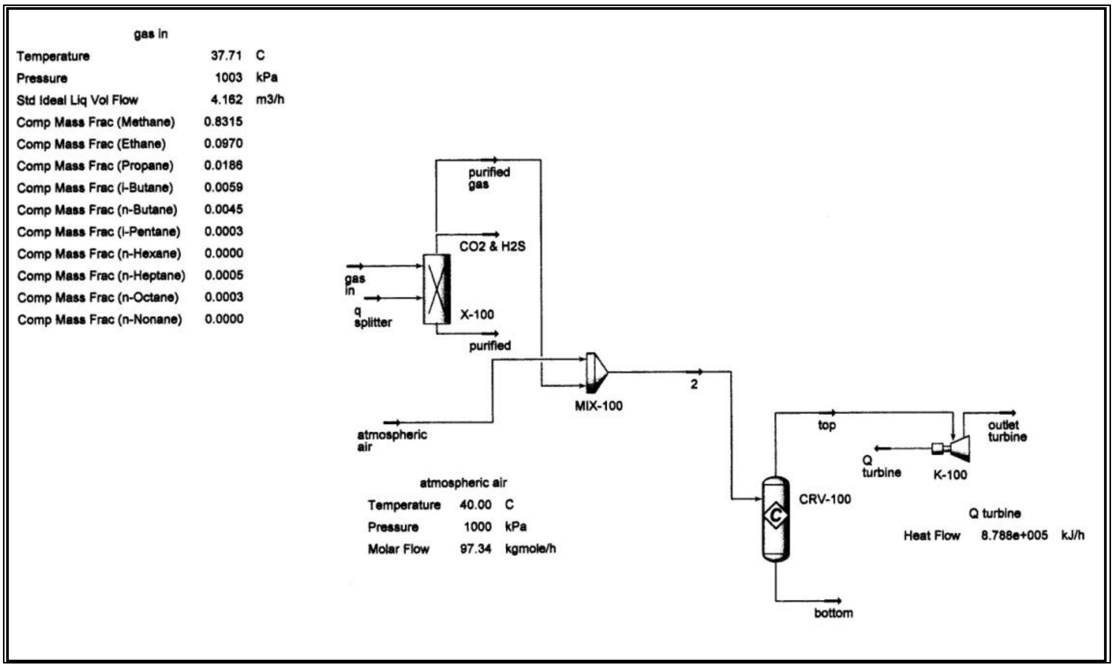


Figure 10: Complete Process Flow Diagram for Electricity Generation by Using Microturbine

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

This thesis has investigated the energy potential from flare gases in the oil and gas facilities, specifically for Duyong Central Processing Platform (DCPP). Microturbine together with the gas conditioning techniques has been selected to convert the energy in the natural gas into electricity. Contaminants such as hydrogen sulphide, carbon dioxide and water vapour that exist together with the natural gas have to be removed in order to utilize the flare gas with microturbine. From the simulation that has been detailed in chapter 3, 244kW of electrical power could be harnessed from the volume of natural gas that currently being flared which is at 1.56 MMscf/d. This amount of energy could reach its peak as much as 325kW when the gas inflow at its maximum which is at 2.0MMscf/d.

Furthermore, this thesis had evaluated the energy potential from the flare gases on the platform economically. In particular, chapter 4 has presented the economic evaluation in detail where the economic tools such as, present worth method, internal rate of return and payback period were used. It is concluded that energy recovery from the flare gases by using the microturbine is a sound investment.

5.1 Recommendation

This thesis has investigated the energy recovery potential with the aid of HYSYS software simulation in steady state mode. However, since the volume and compositions of natural gas varies with time, it is recommended to study these effects in real time where dynamic model functions of simulators can be used.

In this study, it has been assumed that the power generated is required on the platform. Since a project of this magnitude needs a huge capital, it is necessary to investigate the need for electricity thoroughly.

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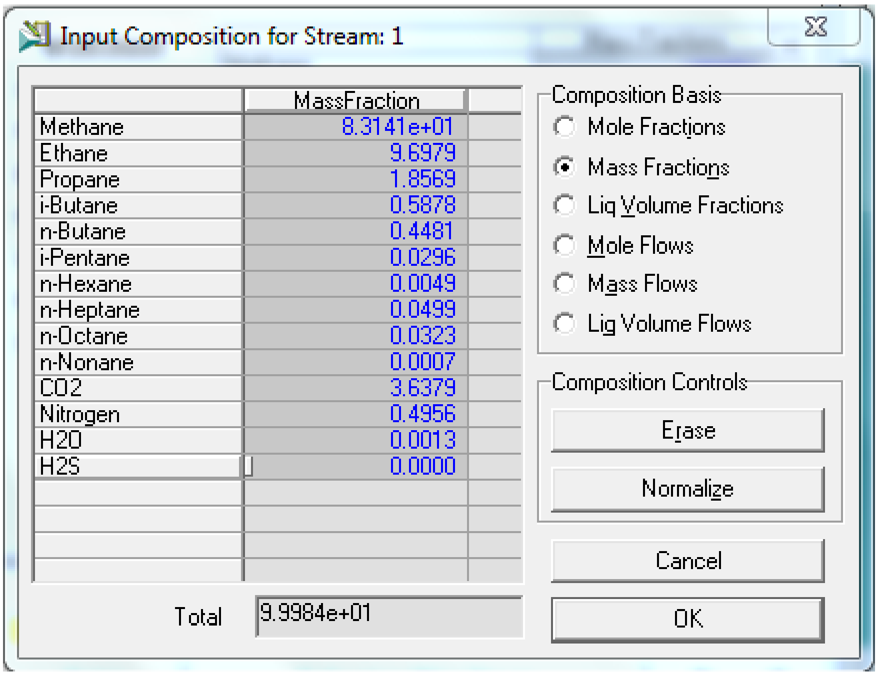
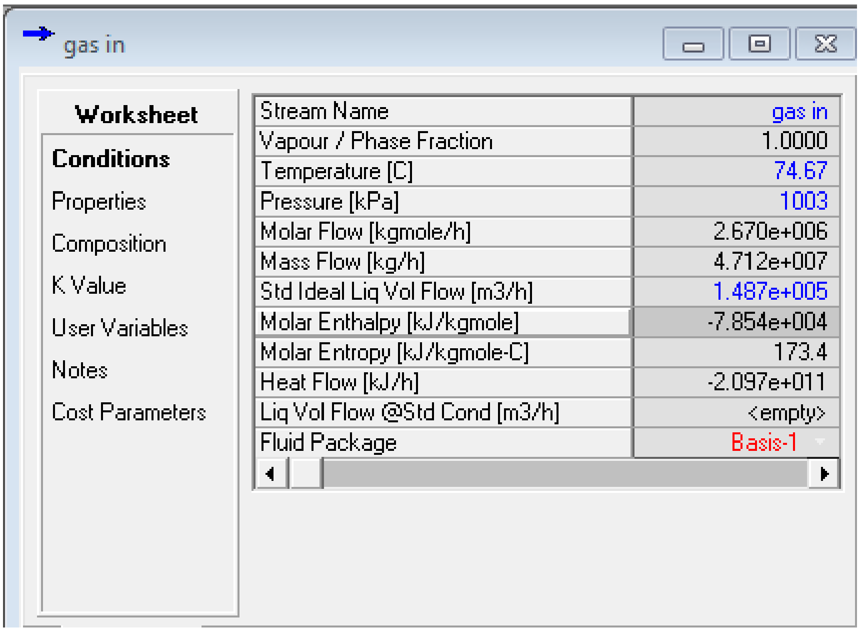
Appendices

Table 12:Input Composition as in HYSYS



	MassFraction
Methane	8.3141e+01
Ethane	9.6979
Propane	1.8569
i-Butane	0.5878
n-Butane	0.4481
i-Pentane	0.0296
n-Hexane	0.0049
n-Heptane	0.0499
n-Octane	0.0323
n-Nonane	0.0007
CO2	3.6379
Nitrogen	0.4956
H2O	0.0013
H2S	0.0000
Total	9.9984e+01

Table 13: Condition of input stream as in HYSYS



Stream Name	gas in
Vapour / Phase Fraction	1.0000
Temperature [C]	74.67
Pressure [kPa]	1003
Molar Flow [kgmole/h]	2.670e+006
Mass Flow [kg/h]	4.712e+007
Std Ideal Liq Vol Flow [m3/h]	1.487e+005
Molar Enthalpy [kJ/kgmole]	-7.854e+004
Molar Entropy [kJ/kgmole-C]	173.4
Heat Flow [kJ/h]	-2.097e+011
Liq Vol Flow @Std Cond [m3/h]	<empty>
Fluid Package	Basis-1

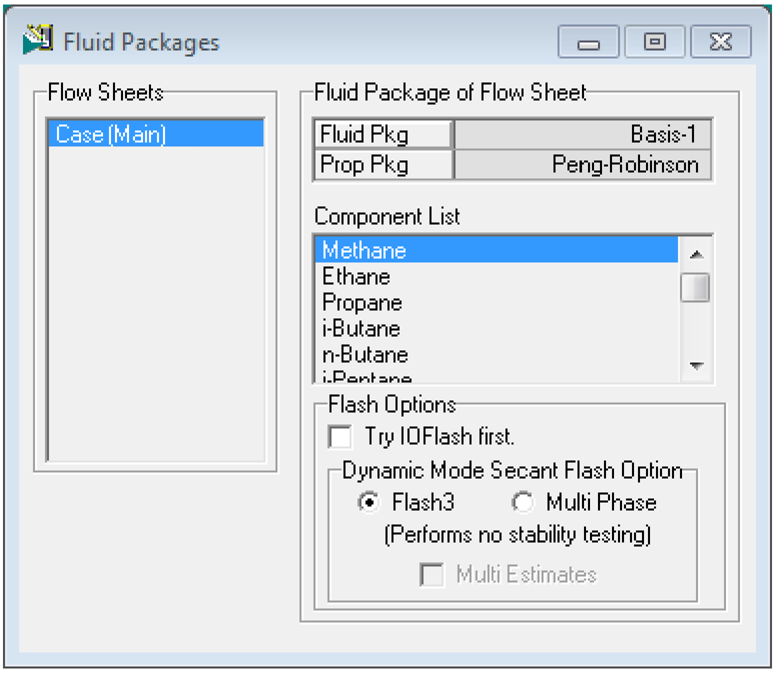


Figure 11: Fluid packages as selected in HYSYS